



Defining long-duration energy storage

Because “more than four hours” isn’t enough

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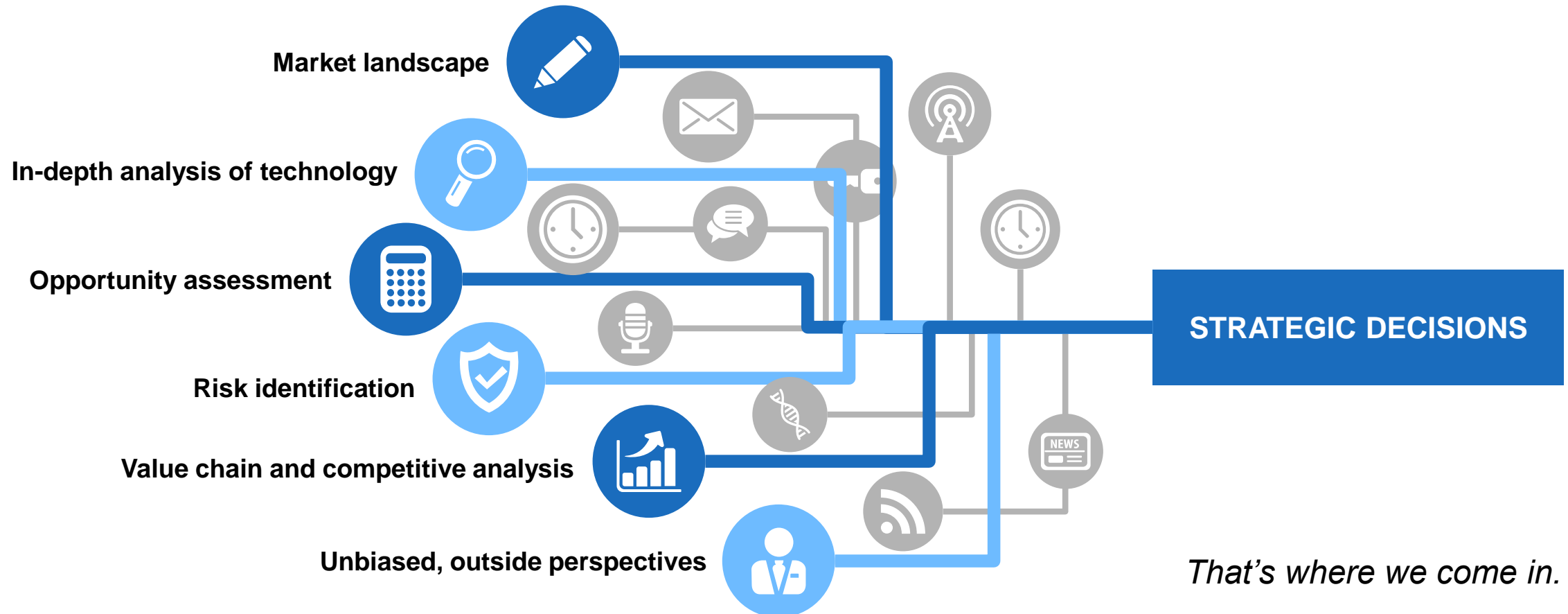
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Making decisions about tech innovation is complicated

An informed decision requires an understanding of:



Agenda

- 1 Changing needs of energy storage
- 2 The energy storage applications map
- 3 FERC 841 and opportunities today

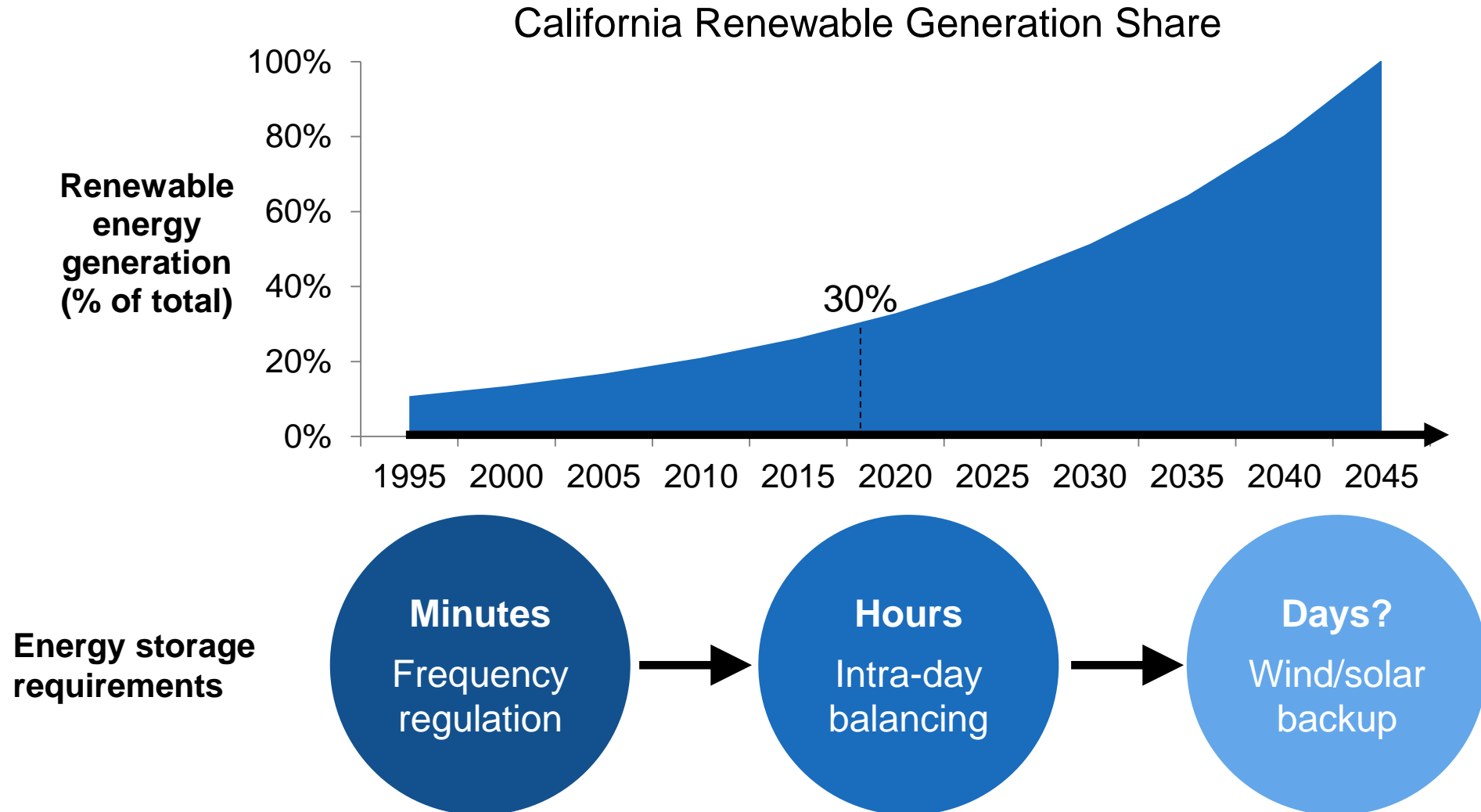


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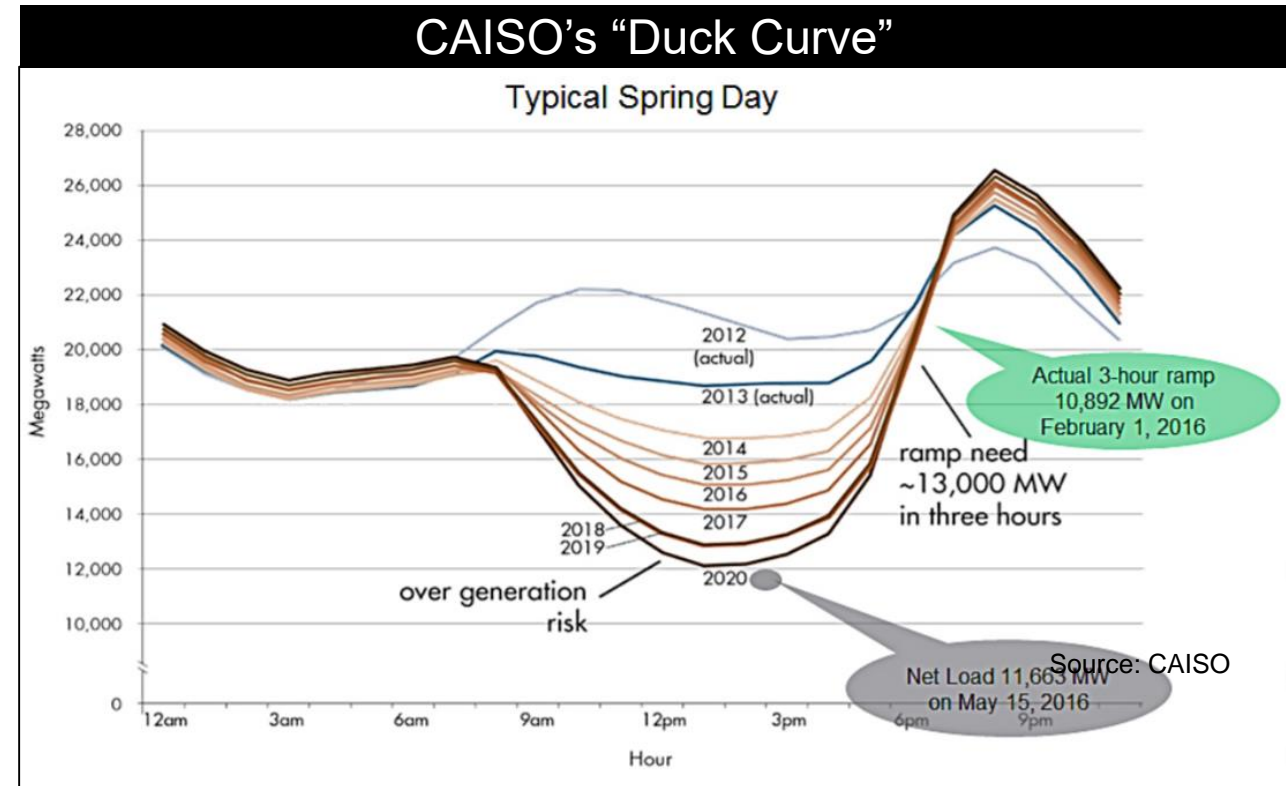
As electricity markets evolve and generation mixes change, so do too the demands put on stationary energy storage



Long-duration storage is increasingly being used to integrate more renewables on the grid by managing generation variability

As wind farms and solar plants become larger and reach greater numbers of deployments, the grid becomes more difficult for independent system operators and regional transmission organizations to manage.

Developers, renewables site owners, and utilities are beginning to use energy storage to manage these ramps and reduce strain on the grid.



High penetrations of solar in the California grid drive midday loads down when solar generation is highest, but as the sun sets around 7 p.m., fossil generators have to come online fast, about one every 15 minutes, to fill the gap

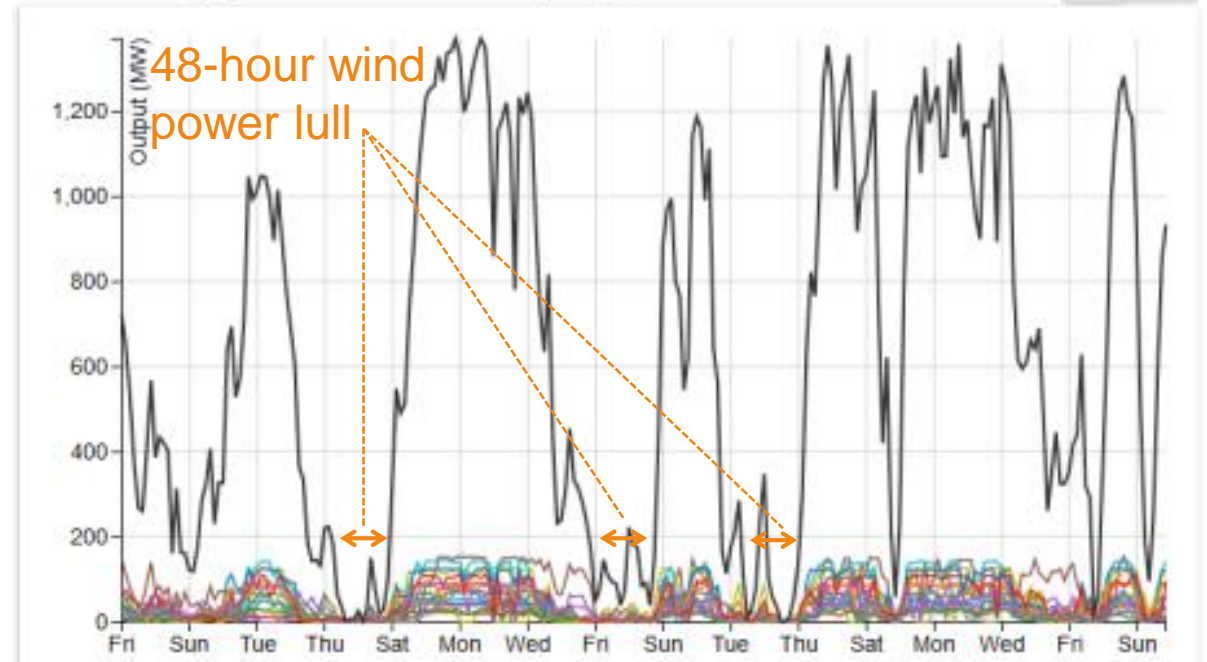
In a similar bid for reliability, grid-tied renewable facilities are using storage to maintain power through long interruptions

One emerging value proposition for long-duration storage that's similar to the microgrid case is renewables backup, where large-scale energy storage is used to turn solar and wind plants that may only run 30% to 50% of the year into reliable 24/7/365 source of power.

Here, storage enables a renewable energy facility to accommodate large-scale variations in weather patterns on days-to-weeks timescales.

South Australia Wind Production

Wind Energy Production During July 2016



Source: Aneroid Energy

In 2016, South Australia suffered significant blackouts due to storms and reductions in wind power output from calms that lasted for days

These applications require energy storage solutions that extend beyond the one- to two-hour timeframes previously employed

All these applications call for long-duration storage, but the timescales, and thus requirements, for that storage are all very different from each other.

Given the many applications calling for long-duration storage, with multiple technologies all claiming to provide long-duration solutions, how can anyone be expected to navigate this landscape?

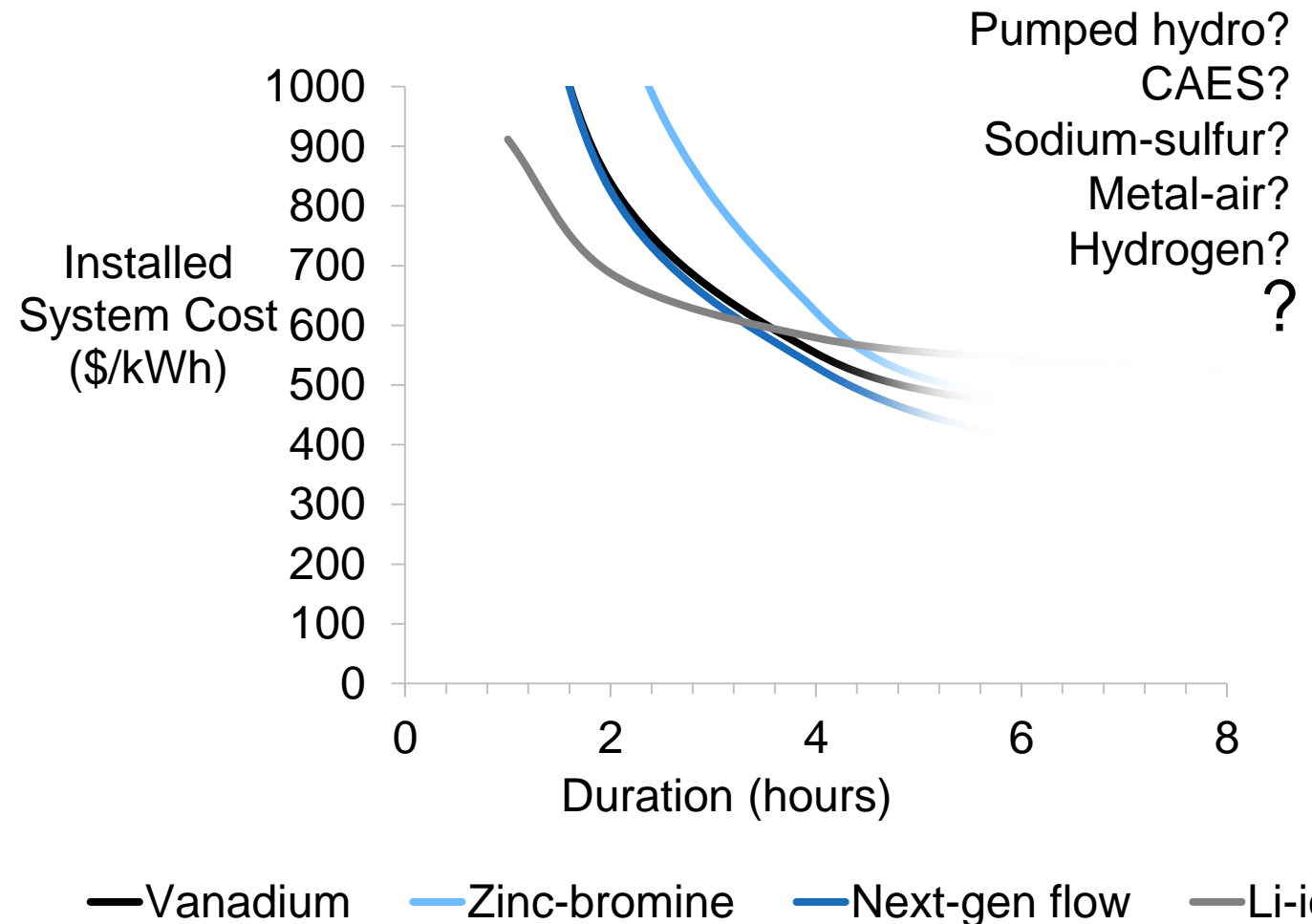


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Methodology: To see which companies will succeed in the long-duration space, we have to look at applications and costs

In order to provide clarity in understanding the long-duration space and which companies and technologies are best-positioned, we need to better define the applications that require long durations.

We'll look to deployed energy storage systems in targeted applications for examples, detail the typical operating parameters of these projects, and evaluate how these project parameters impact costs across a range of technologies for a given long-duration application.

In this report, we'll evaluate the following applications and, over the next few slides, identify the energy storage technologies covered:



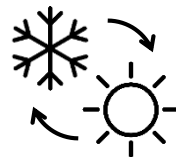
Peaker plant replacement



Renewables backup



Renewables integration



Seasonal energy storage



Microgrid support

Renewables integration represents a heavier-duty and longer-duration case, particularly when integrating solar



Renewables integration focuses on managing and mitigating the aggressive ramping in renewables-heavy grids to ameliorate the “duck curve” issue and as such can cycle often – up to twice a day.

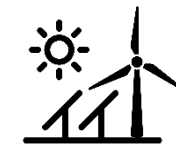
Typical system operation parameters: **four to eight hours discharge duration, 10 MW to 1 GW power rating, 360 to 720 cycles/year**

| Model Parameter | Input 1 | Input 2 |
|--------------------|------------|------------|
| System Size | 100 MW | 1 GW |
| Charge Duration | 6 hours | 6 hours |
| Discharge Duration | 6 hours | 6 hours |
| Cycles per Year | 550 cycles | 550 cycles |



Sumitomo vanadium flow battery

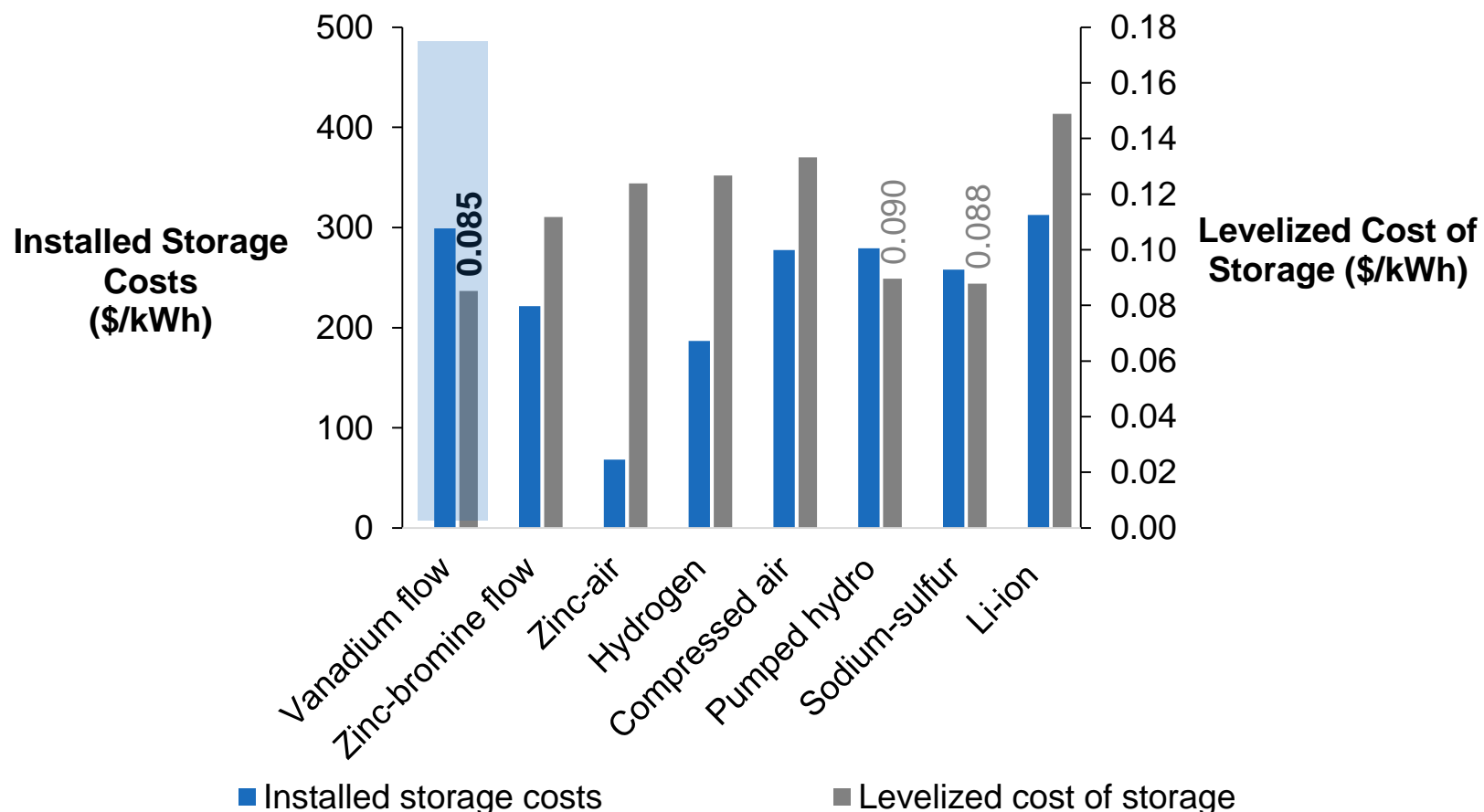
When installed on-site at renewables facilities, flow batteries are the most attractive energy storage option



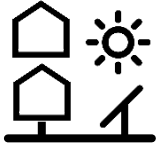
Vanadium flow batteries are efficient and robust enough to handle the cycling demands of renewables integration, leading to the lowest LCOS despite high upfront costs.

With combustion turbines having a [levelized cost of energy from \\$0.085/kWh to \\$0.099/kWh](#), energy storage presents an opportunity for renewables integration.

100 MW, 6-hour charge/discharge, 550 cycles/year



Microgrid energy storage systems help integrate renewables and reduce fossil-fueled generator use

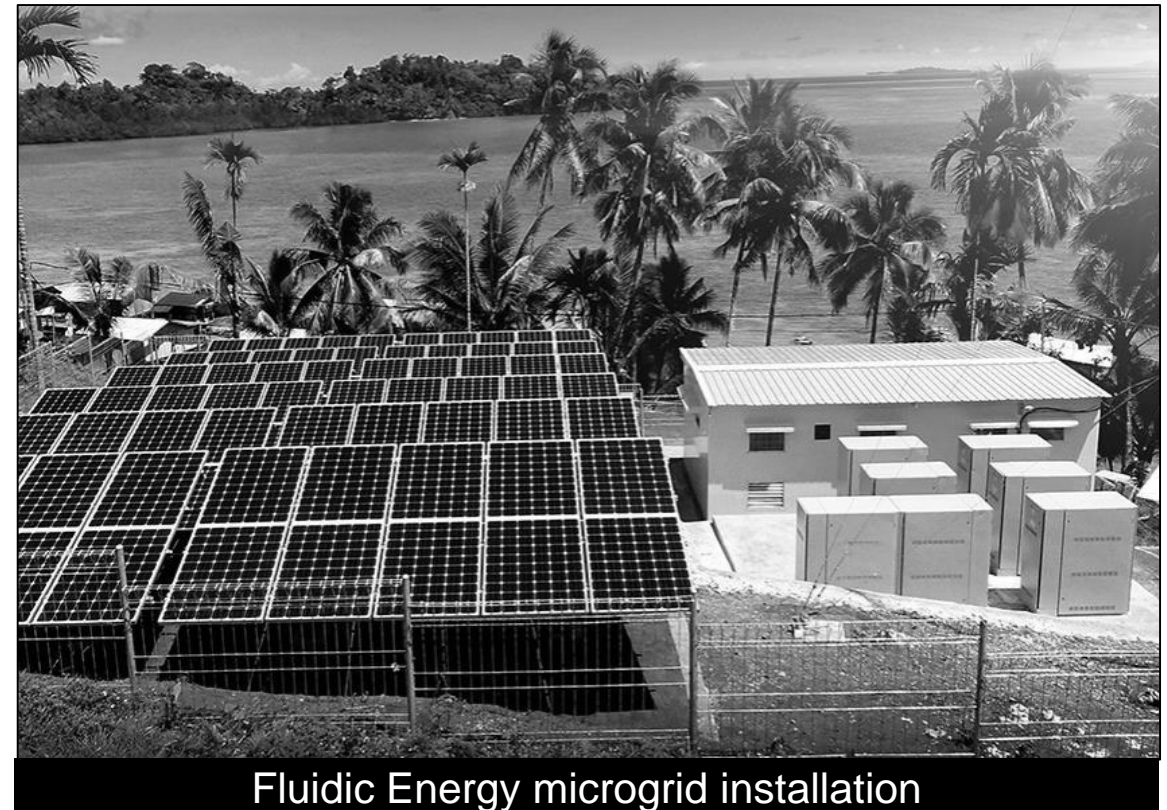


Microgrid energy storage tries to extend the utilization of renewables to reduce or eliminate diesel genset reliance.

In order to capture all the solar produced in a day and discharge it through the night, microgrid energy storage systems often have shorter charge durations than discharge durations.

Typical system operation parameters: **eight to 36 hours, 10 kW to 1 MW, 200 to 365 cycles/year**

| Model Parameter | Input |
|--------------------|------------|
| System Size | 50 kW |
| Charge Duration | 8 hours |
| Discharge Duration | 16 hours |
| Cycles per Year | 365 cycles |



Fluidic Energy microgrid installation

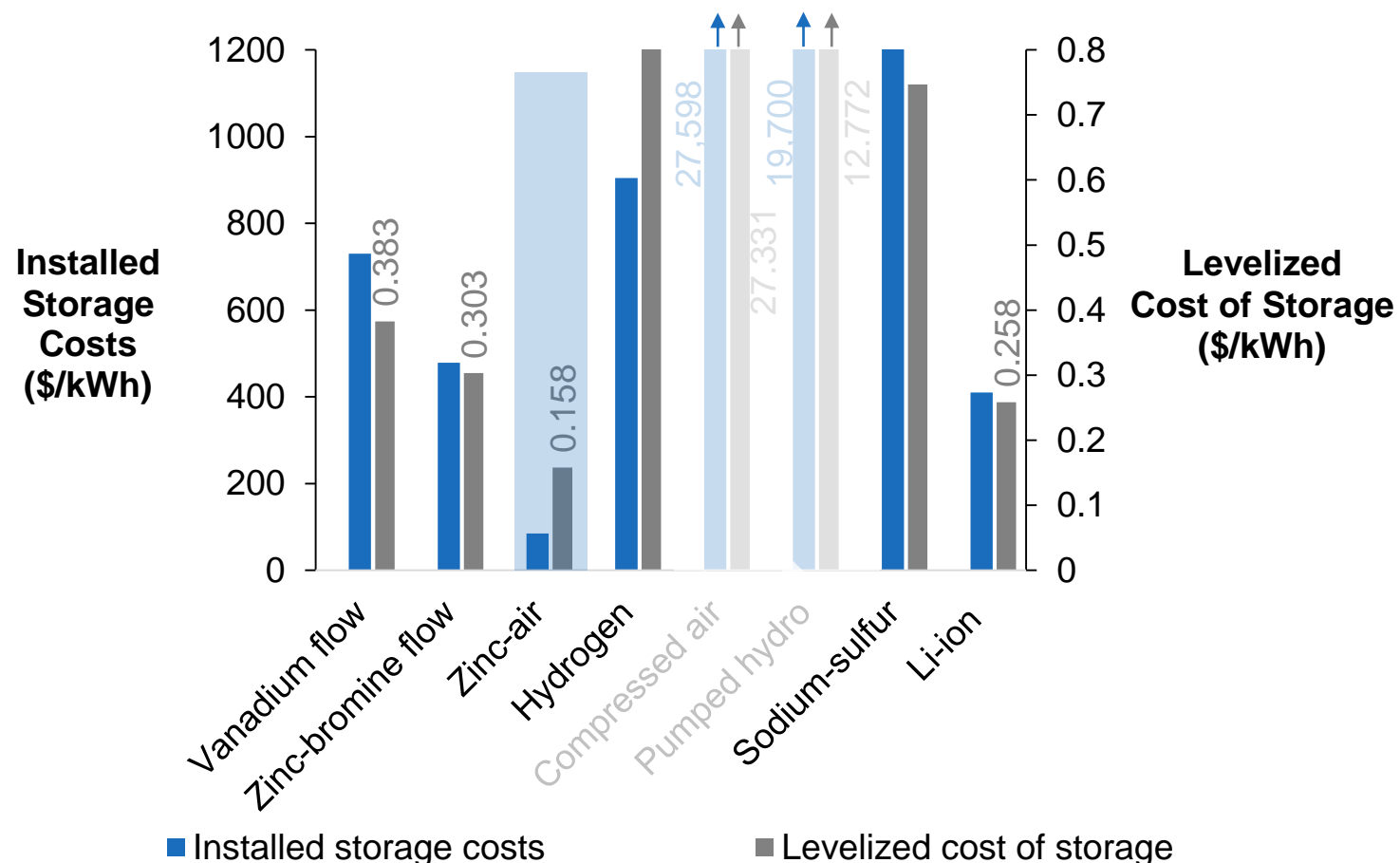
Small scales and long discharge duration favor zinc-air batteries with favorable economics when displacing diesel



While difficult to get right, zinc-air systems use cheap battery components that can offset the higher balance-of-system costs at small scale.

Electricity from diesel generators costs approximately \$0.30/kWh with diesel at \$1/L. With zinc-air storage costing well below that, off-grid microgrids can save money employing energy storage to reduce diesel fuel use.

50 kW, 8-hour charge/16-hour discharge, 365 cycles/year



Renewable energy backup requires long durations to ride through extended lulls in wind and cloud cover in solar



Large-scale weather systems like seasonal clouds and calms can significantly reduce renewable energy installation outputs for days or weeks.

To back these renewable energy facilities up to weather these reductions in output, long-duration systems must be employed, though due to the multiday lengths of discharge cycles, the number of possible annual cycles is limited.

Typical system operation parameters: **24 to 120 hours, 10 MW to 100 MW, 75 to 150 cycles/year**

| Model Parameter | Input |
|--------------------|-----------|
| System Size | 100 MW |
| Charge Duration | 12 hours |
| Discharge Duration | 72 hours |
| Cycles per Year | 52 cycles |



SolarReserve's 24/7 solar power plant

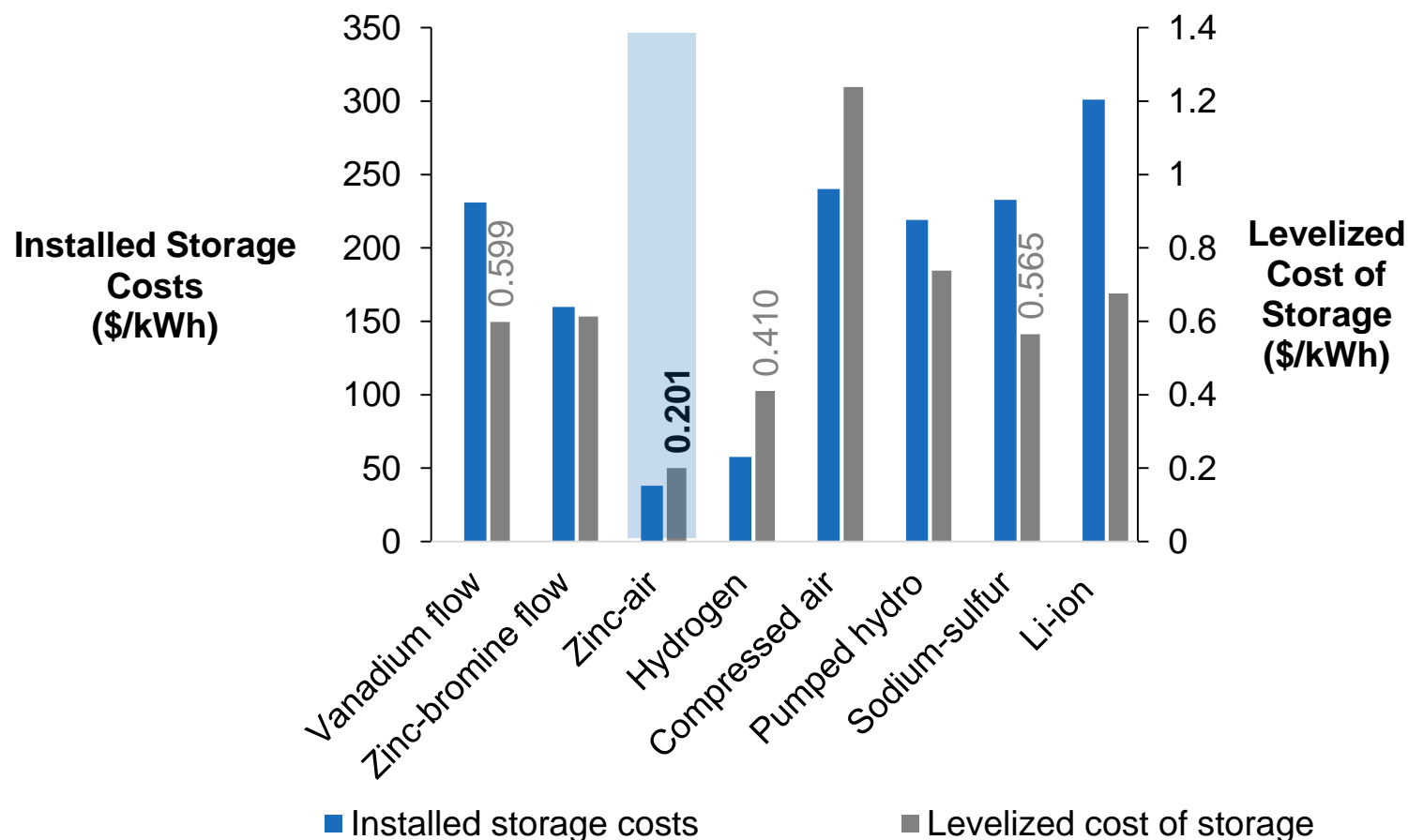
Lowest-cost option for renewables backup is zinc-air batteries, but application is challenged by high costs



Renewable backup systems are cheap to install, but levelized cost of storage is high due to low annual utilization.

Utility matters – increasing asset use from once a week to twice a week reduces LCOS, but costs still remain above \$130/MWh.

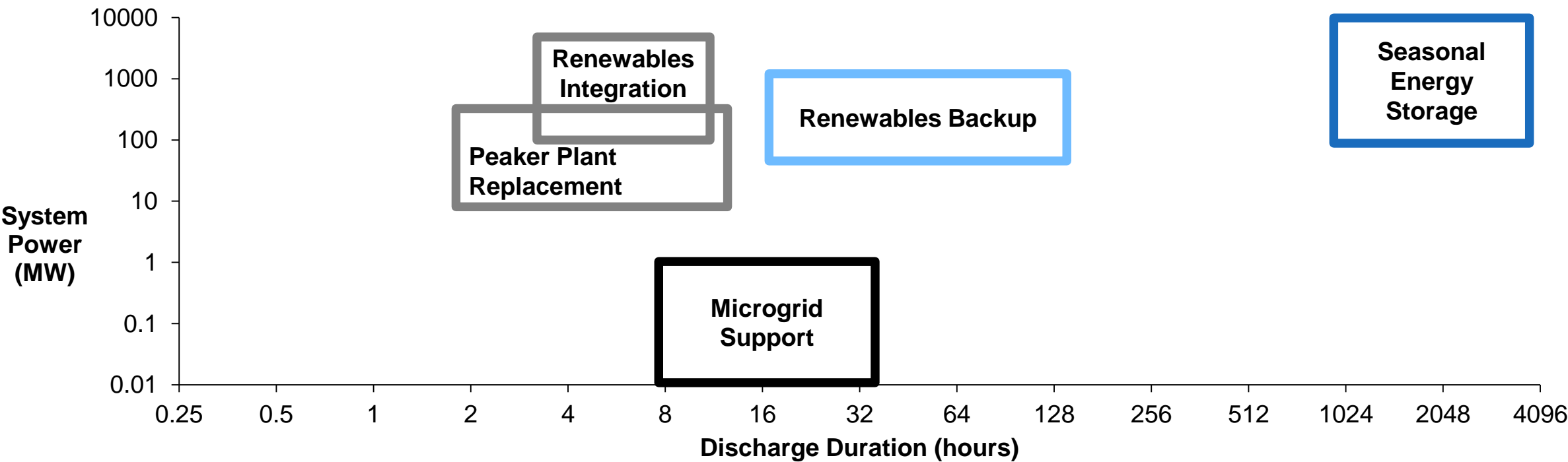
100 MW, 12-hour charge/72-hour discharge, 52 cycles/year



In each application above, we outlined the typical system sizes and durations; plotting those reveals a long-duration storage map

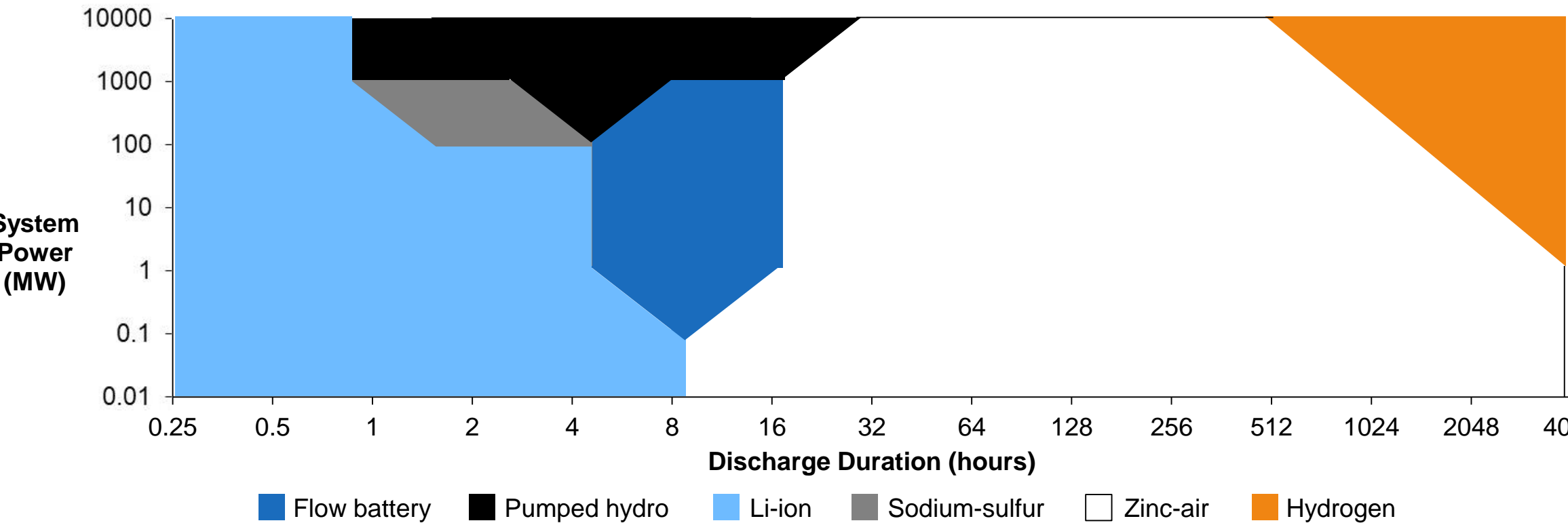
On this map, we have system discharge duration on the x-axis spanning from minutes (0.25 hours) to months (720 hours). On the y-axis is system discharge power, ranging from 10 kW to 10 GW.

A large area of the size-duration landscape isn't covered by applications because not every area corresponds to a problem utilities, developers, and project owners are trying to solve today.



We can use our model to select the lowest-cost energy storage technology for any combination of durations or scales

This map depicts the lowest-cost energy storage technology by system size and discharge duration. Here, charge and discharge durations are equal, and the system cycles either once daily or continuously for durations greater than 12 hours. This is only slightly different than the applications outlined earlier. Li-ion and zinc-air secure the largest areas, but sodium-sulfur and flow hold key positions.



Mapping the lowest-cost energy storage technology onto our applications landscape reveals a competitive battleground

The applications that have value-add economics today are **renewables integration** and **microgrid support**.

These two applications have multiple technologies to choose from depending on project parameters. In terms of next-generation storage technologies, zinc-air and flow batteries are best positioned for growth, though zinc-air may be an underexplored opportunity given the size of the applications space it leads in cost.

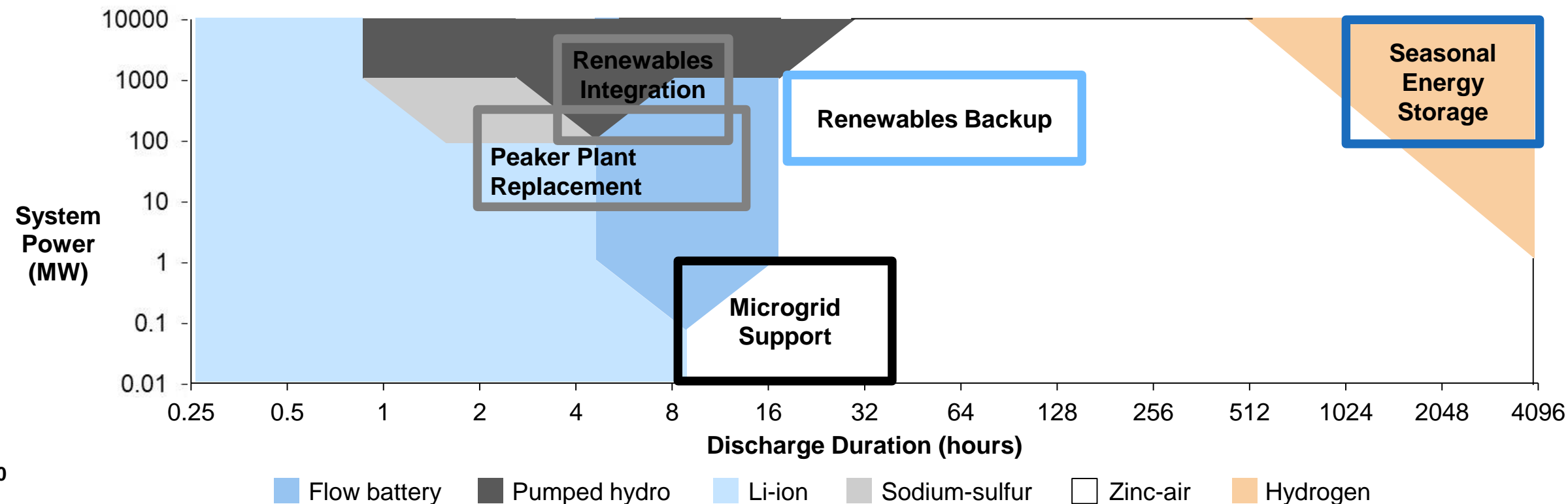


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FERC Order 841 aims to encourage participation of energy storage in markets, but requirements appear different

In Lux’s analysis of FERC Order 841 compliance applications, there appears to be some inconsistencies in how minimum durations are approached. Ancillary service markets seem approachable, with one- or two-hour minimums explicitly stated or implied through market clearing schedules. Capacity markets are a different story, and typically reflect unchanged requirements of fossil generators, leading to much longer durations. Regulated utilities, despite different governing policies, have similar duration specifications.

| Minimum Energy Storage Duration | | |
|---------------------------------|-------------------------------------|------------------|
| ISO/RTO | Ancillary Service Markets | Capacity Markets |
| ISO-NE | 2 hours to qualify as ESR | |
| NYISO | 1 hour to qualify as ESR | 4 hours |
| PJM | | 10 hours |
| SPP | 1 hour | |
| MISO | 1 hour | 4 hours |
| CAISO | | 4 hours |
| Hawaii | 4 hour <i>de facto</i> standard | |
| Arizona | Proposed 5 hour clean peak standard | |



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